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A Unique, Efficient, Implantable, Electromechanical, Total Artificial Heart

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A completely implantable, one piece electromechanical total artificial heart (TAH) intended for permanent human use was developed. It consisted of left and right conically shaped pusher-plate blood pumps sandwiching a thin centerpiece with a compact, efficient electromechanical actuator. The actuator consisted of a direct current brushless motor; a planetary roller screw fit the space between the two conically shaped pusher-plates. The rotational motion of the motor was converted to the rectilinear motion of the rollerscrew to displace the left and right pusher-plates in the left master alternate mode. The diameter of the assembled TAH was 97 mm, with a central thickness of 82 mm. The overall weight was 620 g, with a displaced volume of 510 ml. The pump provided flows of 3–8 L/min with a preload of 1–15 mmHg against an afterload of 100 mmHg. The net efficiency ranged from 15% to 18%. This model showed good fit in the pericardial space of heart transplant recipients (body weight, 77 kg). *ASAIO Transactions* 1991; 37: M238–M240.

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Various types of one piece total artificial hearts (TAHs) intended for permanent human use have been reported, each with anatomic, mechanical, control, and biocompatibility problems.[1,2] The implantable permanent TAH must have 1) good anatomic fit, 2) high performance with high efficiency, 3) long durability (over 2–3 years), and 4) good biocompatibility. To meet these design criteria, a unique, efficient, electromechanical TAH intended for permanent human use was developed.

Materials and Methods

Pumping Unit and Controller

This prototype TAH was a one piece unit with left and right pusher-plate type pumps (63 ml design stroke volume) sandwiching a thin centerpiece (18 mm) with an electromechanical actuator **(Figure 1)**. The pusher-plates were shaped conically to accommodate the electromechanical actuator in the space between them. This configuration minimized the overall volume, particularly the distance between the left and right pumping chambers. Hexsyn rubber was used as the diaphragm because of its high flex life of over 350 million cycles. The blood contacting surface was coated with glutaraldehyde treated calf skin gelatin. The dry gelatin procedure was developed to circumvent the problems with wet gelatin. We used 27 and 23 mm tissue valves in the inlet and outlet ports, respectively.

The electromechanical actuator consisted of a direct current brushless motor (Sierracin/Magnedyne) and a planetary rollerscrew (SKF). The rotational motion of the motor was converted to the rectilinear motion of the rollerscrew[3] to displace the left and right pusher-plates. The pump filled passively, and the TAH was operated in the left master alternate (LMA) fill–empty mode using the rollerscrew and left pusher-plate position signals.

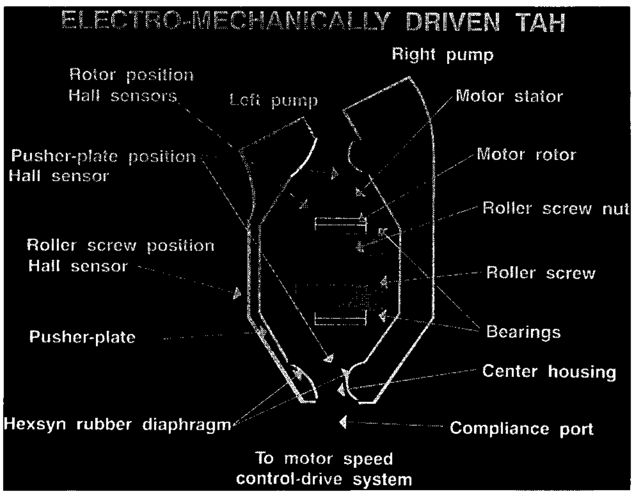

Figure 1. Schematic of a compact, one-piece, electromechanical total artificial heart.

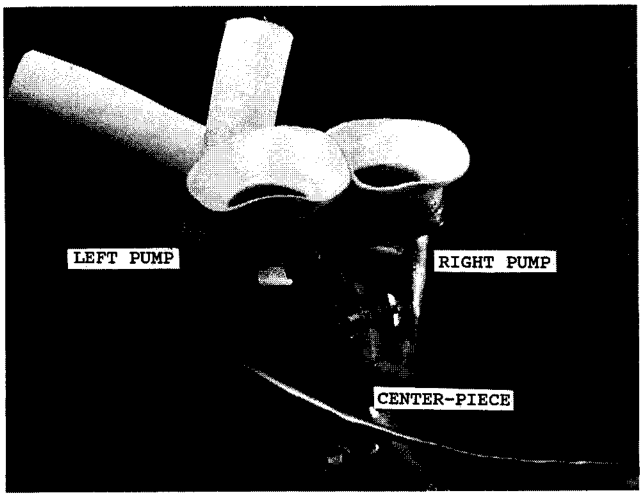

Figure 2. An assembled electromechanical total artificial heart.

Human Anatomic Fit Study

Because of the limitations of using human cadavers, radiographs, and computed tomography, anatomic fit of the prototype TAH was evaluated in heart transplant recipients.[4] Intraoperatively, a silicone model of the prototype TAH was fitted in the pericardial space of heart transplant recipients to optimize port angulation.

In Vitro *Study*

Pump performances, including output capacity, power requirement, efficiency, and dynamic performance were studied in the left–right independent and series mock loops.

Results

Figure 2 shows the electromechanical TAH. The external diameter was 97 mm, with a thickness of 82 mm. The overall weight was 620 g, with a displaced volume of 510 ml. This TAH fit in the pericardial space of patients with average body weights and surface areas of 77 kg and 2.0 m^2, respectively.

The pump can provide flows of 3–8 L/min against a 100 mmHg afterload, with a filling pressure of 1–10 mmHg. The required power range was 7–14 watts, and efficiency, defined as the ratio of pump output power to electrical input power, varied from 15% to 18%. The LMA mode responded well to changes in both right and left atrial pressures.

Summary

The newly designed electromechanical TAH was, first, compact and low volume (achieved through a conical pusher-plate design and by reducing the distance between the left and right inflow ports to 40–50 mm), thus fitting better into the pericardial space of patients. Second, it was able to provide flows of 3-8 L/min with a preload of 1-10 mmHg against an afterload of 100 mmHg and an efficiency of 14-18%. Third, it was controlled and monitored reliably because of the Hall effect position sensors. The LMA mode has advantages in both protecting the lungs and responding to venous return. Fourth, both Hexsyn rubber and rollerscrews have proven durability with more than 2 years of operation. Fifth, the dry gelatin offered excellent biocompatibility by circumventing the sterilization and storage problems of wet gelatin. Because of these features, this TAH will be suitable for permanent support of the end-stage cardiac patient.

References

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